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SHORT COMMUNICATION

The Distribution of *Dryopteris caudipinna* (Dryopteridaceae), a Sexually Reproducing Counterpart of the Apogamous *D. erythrosora*, in Japan

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The distribution of *Dryopteris caudipinna*, a sexually reproducing counterpart of the apogamous species *D. erythrosora*, was investigated by counting the number of spores per sporangium in a large number of herbarium specimens. We discovered a number of new localities for *D. caudipinna*, including most of the major islands in the Izu Island arc (Tokyo Prefecture), and in Chiba, Aichi, Tottori, Yamaguchi, Kochi, Nagasaki, and Fukuoka prefectures. The habitat of *D. caudipinna* tends to be islands and coastal areas in warm temperate regions under the influence of warm currents.

Key words: apogamy, Dryopteridaceae, *Dryopteris caudipinna*, Izu Islands, spores

Dryopteris erythrosora (D. C. Eaton) Kuntze, and its allies (*Dryopteris* sect. *Polystichodris*) diversified in the Japanese archipelago, where there are more than 25 taxa (Iwatsuki 1995), including apogamous triploids (Takamiya 1996). Only two sexual diploid species, which may have been involved in the formation of the apogamous species complex, are recognized in Japan: *D. caudipinna* Nakai, originally described from Hachijojima, and *D. koidzumiana* Tagawa from the Ryukyu Islands. Information on their distribution, especially of the former, has been documented only sporadically or remains unpublished. The number of spores per sporangium can be an indicator of the reproductive mode of most leptosporangiate ferns (Takamiya 1996); the presence of 64 spores usually suggests sexual reproduction, while 32 spores suggests apogamy. In this study, we updated information related to the distribution of these two species mainly by counting the number of spores per sporangium on herbarium specimens.

Originally, *Dryopteris caudipinna* was not recognized as a sexual counterpart of *D. erythrosora*, but was thought to be a relative with narrow pinnules when Nakai (1931) described it. Subsequent studies revealed that *D. erythrosora* is an apogamous triploid (Kurita 1961), and that plants morphologically corresponding to *D. caudipinna* are sexual diploids (Hirabayashi 1970). *Dryopteris* caudipinna tends to have narrower pinnules than *D. erythrosora*, but distinguishing it from the apogamous *D. erythrosora* is not always successful (Yamamoto & Nakaike 1983) as apogamous individuals sometimes have a narrow pinnules and appear similar to *D. caudipinna*. Reliable identification of *D. caudipinna*, therefore, should be based on counting the number of spores per sporangium, counting chromosomes, or determining the size of the genome. In other words, the taxon is defined by its reproductive mode, not by morphological characters.

Previously known localities for *Dryopteris caudipinna*, confirmed by spore or chromosome counts, include Tsukuba-shrine in Ibaraki Prefecture (Fujimoto 1998), Jinmuji in Kanagawa

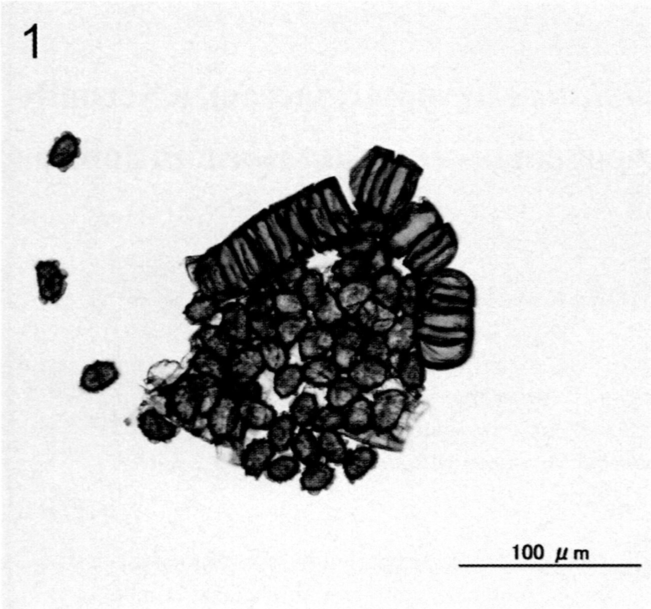


FIG. 1. Example of 64 spores per sporangium, indicating sexual reproduction (*S. Tsutsui 17349*, TNS [VS-573601]).

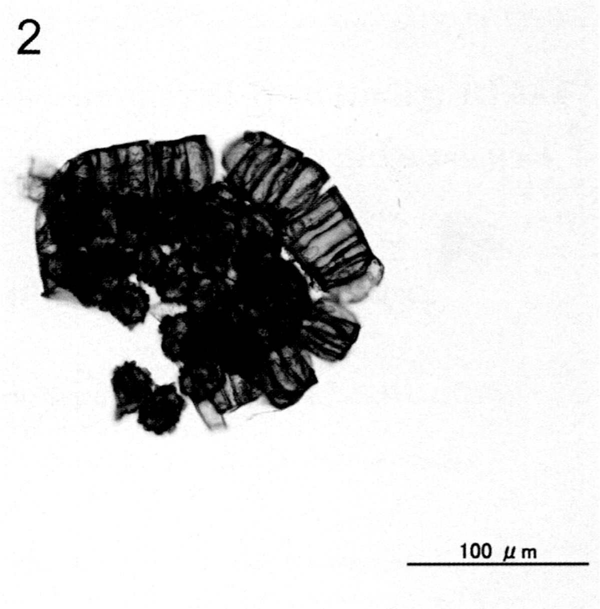


FIG. 2. Example of 32 spores per sporangium, indicating apogamous reproduction (*S. Kobayashi 2993*, TNS [VS-573459]).

Prefecture (Yamamoto & Omori 1991), Oshima (Nakaike & Yamamoto 1984) and Hachijojima (Hirabayashi 1970, Yamamoto & Nakaike 1983) in Tokyo Prefecture, Kanmuri Island in Kyoto Prefecture (Mitsuda 1990), the Shimane Peninsula in Shimane Prefecture (Miyamoto & Nakamura 1990), and Kirishima in Miyazaki and Kagoshima Prefectures (Miyamoto & Nakamura 1990). According to Iwatsuki (1995), the distribution of *D. caudipinna* is confined to the Izu Islands and the Miura and Izu peninsulas. Although both Hirabayashi (1974) and Miyamoto & Nakamura (1990) published distribution maps of *D. caudipinna*, it is unclear whether they examined spores or counted chromosomes, as they did not state the sources of their data.

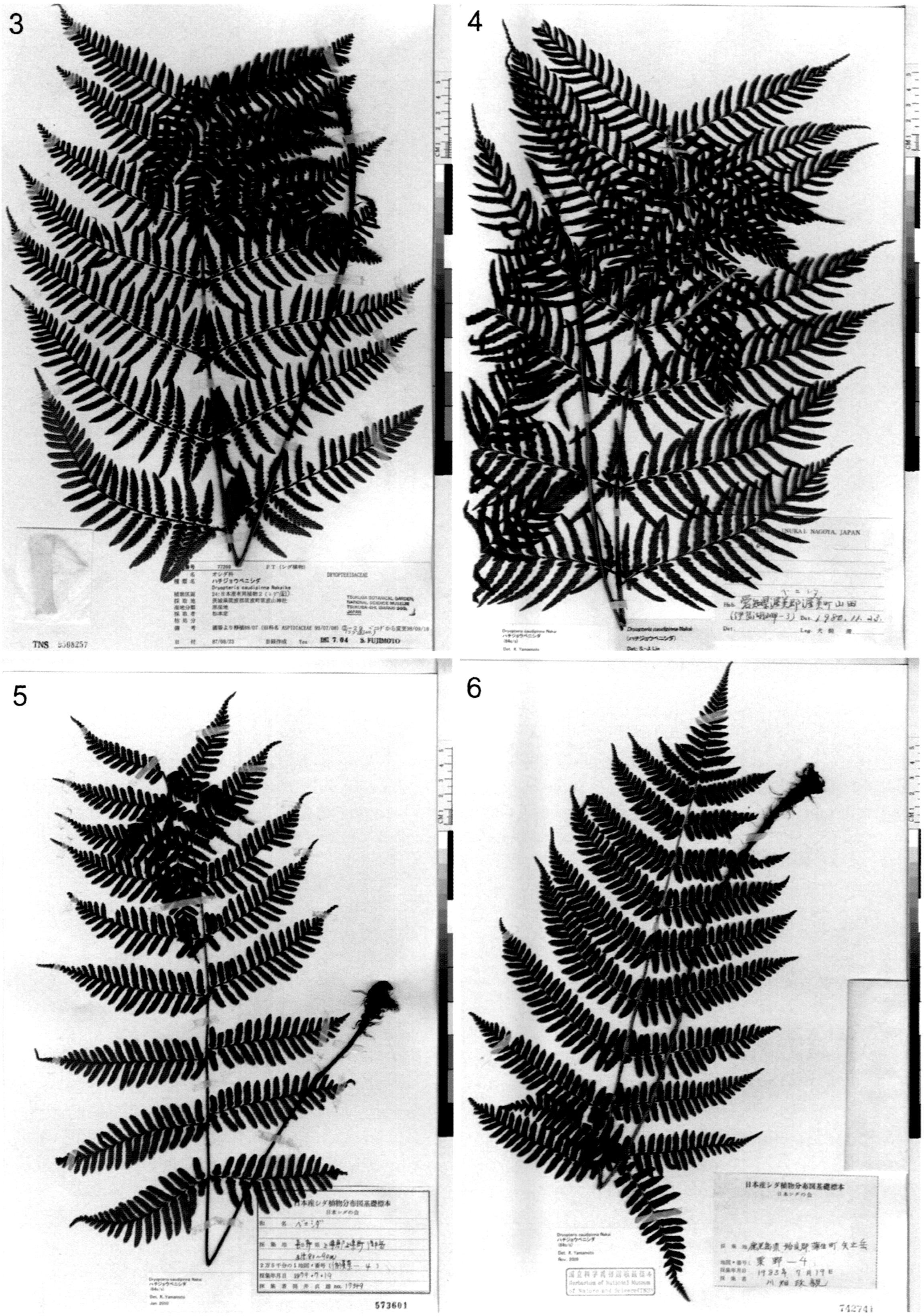
Materials and Methods

Candidate specimens of *Dryopteris caudipinna*, based on frond shape, were selected from approximately 3,500 sheets of *D. erythrosora* and *D. caudipinna* deposited in the National Museum of Nature and Science (TNS) and the Makino Herbarium of Tokyo Metropolitan University (MAK). The number of spores per sporangium was determined under a stereomicroscope for all candidates, unless they were uncountable. For specimens from the Izu Islands, except Oshima and Hachijo-jima, for which comprehensive spore counts had already been made, all of the available specimens were examined to determine the general ratio of sexual to apogamous individuals on the islands.

Results

The spore number per sporangium was determined for approximately 500 sheets of the selected specimens. Among them, 241 specimens had 64 spores per sporangium while about 50 specimens had 32 spores per sporangium. The spores of the remaining specimens were uncountable. Sporangia taken from the following specimens contained 64 spores; their morphological characters matched those of typical *D. caudipinna*. Specimens from previously known localities are excluded from the list.

JAPAN. **Honshu.** Ibaraki Pref.: Nishiibaraki-gun, Iwama-machi, Yamane, 1981-11-08, *M. Yasu s.n.* (TNS [VS-934523]); [Makabe-gun] Makabe-machi, Sakayori–Shiio, Yakuoin, 1973-12-02, *H. Ito s.n.* (TNS [VS-



FIGS. 3–6. Representative specimens of *Dryopteris caudipinna*. **3.** Ibaraki Prefecture, Tsukuba-shi, Tsukuba Shrine, 1987-08-23, *S. Matsumoto s.n.*, living collection of the Tsukuba Botanical Garden 77398, (TNS [VS-9508257]). **4.** Aichi Prefecture, Atsumi-gun, Atsumi-cho, Yamada, 1980-11-23, *K. Inukai 4201* (TNS [VS-550286]). **5.** Nagasaki Prefecture, Tsushima Island, Kamiagata-gun, Kamiagata-cho, Mitake, altitude 80–90 m, 1979-07-19, *S. Tsutsui 17349* (TNS [VS-573601]). **6.** Kagoshima Prefecture, Aira-gun, Kamo-cho, Yadome-dake, 1983-07-19, *M. Kawabata s.n.* (TNS [VS-742741]).

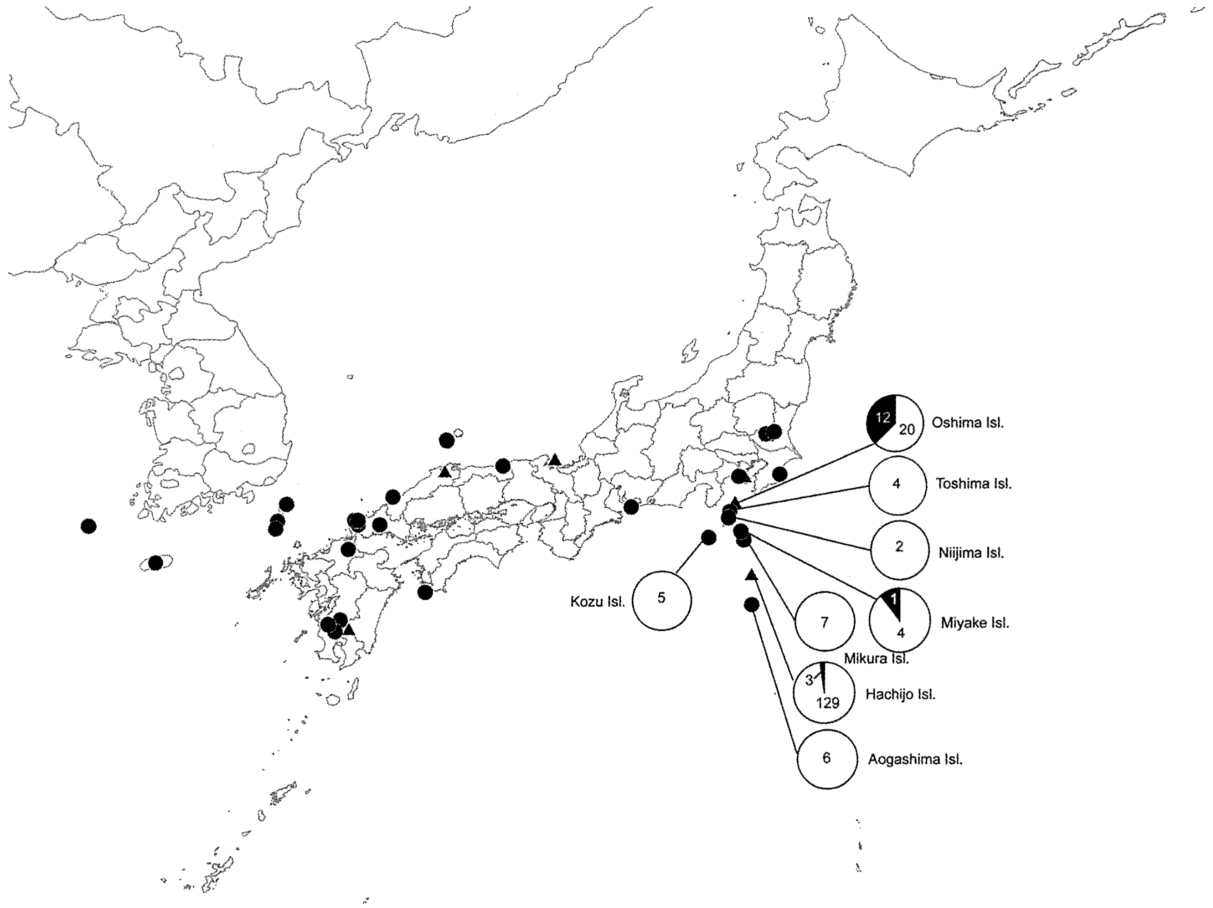


FIG. 7. Distribution map of *Dryopteris caudipinna*. Triangles: previously known localities; Circles: newly recorded localities from this study. Pie charts for Izu islands show approximate ratio of sexual to apogamous individuals (white: 64 spores per sporangium, black: 32 spores per sporangium). Counts are based on Nakaike & Yamamoto (1984) for Oshima and on Yamamoto & Nakaike (1983) for Hachijojima, and on our spore observations for the remaining islands.

1038281]). —Chiba Pref.: Chosei-gun, Ichinomiya-machi, Gundari-yama, 2010-03-08, *K. Yamamoto & A. Ebihara 100308G1-8, 14, 15, 18, 24, 25 & 27* (MAK). —Tokyo Pref.: Toshima Isl.: 1933-07-30, *Y. Jotani, 8202* (TNS [VS-815690]); 1933-07-31, *Y. Jotani s.n.* (TNS [VS-121073]; *Y. Jotani 8207* (TNS [VS-815683]); *Y. Jotani 8210* (TNS [VS-815979]); 1957-07-18, *Y. Jotani 26210* (TNS [VS-815688]). Niijima Isl., Hon-mura, 1981-05-04, *H. Endo s.n.* (TNS [VS-601629]); 1981-05-??, *H. Endo s.n.* (TNS [VS-931539]). Kozushima Isl., Tenjo-san, 1936-07-24, *Y. Jotani 6312* (TNS [VS-815697]); *Y. Jotani 6313* (TNS [VS-815698]); precise locality unknown, 1936-07-26, *Y. Jotani 6311* (TNS [VS-815695]); precise locality unknown, 1966-07-26 to 1966-08-03, *H. Ohba 3018* (TNS [VS-173140, 222713]). Mikurajima Isl., Sato, 1934-07-26, *Y. Jotani 10816* (TNS [VS-121076]); *Y. Jotani 10818* (TNS [VS-815794]); 1934-07-27, *Y. Jotani 10353* (TNS [VS-815792]); Oyama, 1934-07-26, *Y. Jotani 10817* (TNS [VS-815973]); precise locality unknown, 1967-07-29, *Y. Jotani & al. 1279* (TNS [VS-815788]); 1967-07-31, *T. Matsuoka 1104* (TNS [VS-815787]); 1967-08-02, *K. Inoue s.n.* (TNS [VS-1017491]). Miyakejima, Oyama, 1932-08-17, *Y. Jotani 5034* (TNS [VS-815708]); Oyama, alt. 300 m, 1980-10-10, *H. Hatta & S. Matsumoto, living collection of Tsukuba Botanical Garden 13490* (TNS [VS-9508224, 9508226]); precise locality unknown, 1936-07-11, *K. Hayashi s.n.* (TNS [VS-56244]); 1961-04-02, *S. Otaki 3058* (TNS [VS-1038468]); 1964-07-??, *collector unknown s.n.* (TNS [VS-815713]); 1964-07-10, *collector unknown s.n.* (TNS [VS-816077, 816078]). Aogashima, Ikenosawa, 1958-07-20, *Y. Jotani 27607* (TNS [VS-815715, 815716, 815967, 815968]); 1977-10-31, *M. Kato & E. Miki 112* (TNS [VS-369811]); Todaisyo-jinjya, 1988-12-21, *T. Shimakawa s.n.* (TNS [VS-522201]). —Kanagawa Pref.: [Fujisawa-shi] Enoshima, 1979-09-18, *M. Minemura s.n.* (TNS [VS-461080]). —Aichi Pref.: Atsumi-gun, Atsumi-cho, Yamada, 1980-11-23, *K. Inukai 4201* (TNS [VS-550286]). —Tottori Pref.: [Iwami-gun, Fukube-mura] Mani-san, 1931-11-08, *N. Hiratsuka s.n.* (TNS [VS-512216]). —Shimane Pref.: Masuda-shi, Takashima, 1980-10-10, *N. Miake s.n.* (TNS [VS-449584]). Oki Islands, Nishinoshima, Oki-gun, Nishinoshima-cho, Mita, Takuhi-yama, 2008-07-01, *Y. Kazumi s.n.* (TNS [VS-1105395]). —Yamaguchi Pref.: Yamaguchi-shi, Niho, Asaji River, 1993-02-20, *H. Masaki s.n.* (TNS [VS-745192]); 1993-08-12, *H. Masaki s.n.* (TNS [VS-745190]). —Toyoura-gun. [Toyota-cho,] Toyotanaka-mura, 1947-08-23, *K. Oka 1229* (TNS [VS-276102]); Toyoura-gun, Hohoku-cho, Awano, midstream of Futanoi River, 1993-08-30, *H. Masaki s.n.* (TNS [VS-745191]); Otsu-gun, Yuya-cho, Sakane-ue, 1992-08-22, *H. Masaki s.n.* (TNS [VS-745177, 745178]). **Shikoku.** Kochi Pref.: Sukumo-shi, Okinoshima Isl., 1971-07-23, *T. Inobe s.n.* (TNS [VS-1038280]). **Kyushu.** Fukuoka Pref.: [Tagawa-gun, Kawara-machi,] Kawara-dake, 1937-08-26, *M. Irie s.n.* (TNS [VS-513221]); 1951-08-26, *H. Ouchi s.n.* (TNS [VS-100314]). —Nagasaki Pref.: Tsushima Isl., Kamiagata-gun, Kamitsushima-cho, Izumi, alt. 40–50 m, 1979-07-21, *S. Tsutsui 17479* (TNS [VS-573603]); Kamiagata-gun, Mine-mura, Kamizato, along Shishinouchi-kawa alt. 60 m, 1979-07-19, *S. Tsutsui 17322* (TNS [VS-573599]); Kamiagata-gun, Kamitsushima-cho, Eko, alt. 20–30 m, 1979-07-20, *S. Tsutsui 17432* (TNS [VS-573602]); Kamiagata-gun, Kamiagata-cho, Mitake, alt. 80–90 m, 1979-07-19, *S. Tsutsui 17349* (TNS [VS-573601]); Kamiagata-gun, Kamiagata-cho, Mitake, alt. 200–400 m, 1968-09-28, *S. Tsutsui s.n.* (TNS [VS-204608]); Shimoagata-gun, Izauhara-cho, Ariake-yama,, 1968-09-23, *H. Koyama 2819* (TNS [VS-204386]); 1978-02-26, *S. Tsutsui 15131* (TNS [VS-573596]); Tsushima-shi, Mitsushima-cho, Kanedajo, 2007-10-09, *K. Fuse 292* (TNS [VS-768795]); Tsushima-shi, Izuhara-cho, Nainkawa, 2007-10-06, *K. Fuse 182* (TNS [VS-768813]). —Kagoshima Pref.: Okuchi-shi, Manegahira, 1959-08-22, *T. Yamanaka s.n.* (TNS [VS-734596]); Aira-gun, Kamo-cho, Yadome-dake, 1983-07-19, *M. Kawabata s.n.* (TNS [VS-742738, 742740, 742741]); [Izumi-shi,] Jonodan–Shibi–Miyanojo, 1957-08-15, *S. Kurata 882* (TNS [VS-724546]).

SOUTH KOREA. Chollanam-do: Soheuksan-do Isl., 1949-08-05, *O. Yongsokh 8098* (TNS [VS-151180]). —Cheju-do: Cheju-do Isl., 1962-07-28, *S.-Y. Oh 2673* (TNS [VS-1038337]).

Discussion

We confirmed the presence of *Dryopteris caudipinna* in 13 prefectures of Japan and on two Korean islands. The occurrence in seven prefectures in Japan and in Korea represent new range extensions. Except for Shikinejima, which lacked specimens with countable spores, we also confirmed its presence on all of the major Izu Islands. Our investigation extended the distribution range north to Iwama in Ibaraki Prefecture, east to Gundari-yama in Chiba Prefecture, south to Yadome-dake in Kagoshima Prefecture, and west to Soheuksan-do, Korea. In contrast to the wide distribution of *D. erythrosora*, which occurs throughout the warm temperature region of Japan (Kurata & Nakaike 1985), *Dryopteris caudipinna* is distributed on islands and in coastal areas under the influence of the warm Kuroshio and Tsushima currents, although it also occurs in mountainous areas on Kyushu at its southern limit of distribution. The sexually reproducing *D. caudipinna* usually occurs within *Castanopsis* forests, and in the Kanto district (northern limit) it is mostly in well preserved precinct groves. The distribution of *D. caudipinna*, however, does not appear to be simply delimited by climatic conditions, because it has not been found on the Izu and Kii peninsulas, which probably share similar meteorological conditions with the localities where it does grow (for the Izu Peninsula, see Nakaike *et al.* 1984). *Dryopteris caudipinna* normally forms mixed populations with the apogamous *D. erythrosora*, although pure populations of sexual individuals (*D. caudipinna*) exceptionally occur on Hachijojima (Yamamoto & Nakaike 1983), Toshima, Niijima, Kozushima, Mikurajima, and Aogashima Islands. The ecological and historical factors that determine the ratio of sexual to apogamous forms are still unclear.

The relationship between the two sexual diploid taxa, *Dryopteris caudipinna* and *D. koidzumiana*, have not been carefully studied. The latter is usually treated as endemic to the Ryukyu Islands, and is characterized by the abruptly narrowed apex of the pinnae. The distributions of the two species apparently do not overlap, but the difference in the morphology of their fronds is quite subtle. At present, we have little biological evidence for the two sexually reproducing diploids. The difficulty in distinguishing *D. caudipinna* from *D. erythrosora* may arise from the fact that they share the same alleles. Future analyses of allelic diversity with ample sampling should be performed in mixed populations of sexual/apogamous individuals and the two sexual diploids.

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